

Effect of Light-tip Distance on the Shear Bond Strengths of Composite Resin

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Abstract: The purpose of this study was to assess the effect of light-tip distance on the shear bond strength and failure site of brackets cured with three different light curing units: a high-intensity halogen (Astralis 10, 10-second curing), a light-emitting diode (LED, e-Light, six-second curing), and a plasma arc (PAC System, four-second curing). One hundred and thirty-five bovine permanent mandibular incisors were randomly allocated to nine groups of 15 specimens each. Stainless steel brackets were bonded with a composite resin to the teeth, and each curing light was tested at zero, three, and six mm from the bracket. After bonding, all samples were stored in distilled water at room temperature for 24 hours and subsequently tested for shear bond strength. When the three light curing units were compared at a light-tip distance of zero mm, the three lights showed no significantly different shear bond strengths. At light-tip distances of three and six mm, no significant differences were found between the halogen and plasma arc lights, but both lights showed significantly higher shear bond strengths than the LED light. When evaluating the effect of the light-tip distance on each light curing unit, the halogen light showed no significant differences between the three distances. However, the LED light produced significantly lower shear bond strengths at a greater light-tip distance, and the plasma arc lamp showed significantly higher shear bond strengths at a greater light-tip distance. In hard-to-reach areas, the use of PAC system is suggested, whereas the LED evaluated in this study is not recommended. (*Angle Orthod* 2005;75:386–391.)

Key Words: Bond strength; Light-tip distance; Light curing units; Composite resins; High-intensity light curing

INTRODUCTION

Light-cured composite resins provide a reduced risk of contamination, consistent handling characteristics, permit immediate archwire insertion, and give virtually unlimited working time.¹ However, according to the manufacturers' guidelines, visible light curing units require 20 seconds to cure orthodontic composite resins and 40 seconds to light cure resin-modified glass ionomers per bracket.² This pro-

longed curing time is uncomfortable for the patient, impractical with children, and inconvenient for the clinician.^{3,4} Various attempts have been made to accelerate the speed of the light curing process by using a larger light guide or laser devices.^{5–9}

In recent years, xenon plasma lights were introduced for high-intensity curing of orthodontic bonding materials.^{2,10–13} The advantage of this high-intensity light is that the same amount of total light energy can be delivered to the composite in a much shorter time period.¹² Claims of exposure times of three to five seconds have been made for bonding brackets with the plasma arc light curing system, with shorter times for ceramic brackets.¹⁴ Previous investigations generally have reported no significant differences in bond strengths and failure sites of brackets cured with the plasma arc light compared with brackets cured with conventional halogen lights, both in vitro and in vivo.^{2,11–13,15,16}

The innovative light-emitting diode (LED) technology, based on semiconductors, has opened new and interesting views in the field of photopolymerization. LEDs add the advantages of a soft-start polymerization, safety, efficiency, economy, and the longer lifetime of LED light.¹⁷ Despite their lower light emission, LEDs are capable of a poly-

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merization qualitatively comparable with other light sources¹⁸ or slightly lower.¹⁹ In addition, the temperature increase is significantly lower and does not pose a threat to the pulpal tissue.^{20,21} Previous investigations comparing the shear bond strengths of brackets cured with LED with those of brackets cured with conventional halogen lights showed no significant differences.^{22,23} Other studies reported significantly lower bond strengths with the LED when used for 10 seconds.^{24,25} However, in both studies all the bond strengths were above eight MPa and therefore clinically acceptable, even with a 10-second cure.

The degree to which these bonding materials cure depends on the intensity and quality of light to which they are exposed and the curing time. Once the light has left the curing unit, factors such as composite type, composite shade, thickness of resin increment or overlying tooth structure, the distance and orientation of the light tip, and the diameter of the light tip may reduce intensity and provide a lower degree of polymerization.²⁶ The inability to place a light tip in close approximation to the composite resin may affect the resultant polymerization and clinical durability.²⁷

To date, there are no studies that have evaluated the effect of light-tip distance on the shear bond strength of orthodontic brackets cured with halogen, LED, and plasma arc lights. Accordingly, the purpose of this study was to evaluate the effects of different light-tip distances on the shear bond strength and site of bond failure of brackets bonded with a composite resin and cured with halogen, LED, and plasma arc lights. The null hypothesis of the study was that there is no significant difference in bond strength and debond site location among brackets bonded with the halogen light used for 10 seconds, the LED light used for six seconds, and the plasma arc light used for four seconds at different light-tip distances.

MATERIALS AND METHODS

Teeth

A total of 135 freshly extracted bovine permanent mandibular incisors were collected from a local slaughterhouse and stored in a solution of 0.1% thymol for one month at 4°C. The inclusion criteria included intact buccal enamel with no cracks from extraction and no caries. The teeth were randomly divided into nine different groups of 15 each as defined in Figure 1. The teeth were cleansed of soft tissue and embedded in cold-curing, fast-setting acrylic (SG 130, Ebalta, Rothenburg/Tauber, Germany) thus allowing the buccal surface of enamel to be exposed. Each tooth was oriented so that its labial surface was parallel to the shearing force.

Brackets

All 135 teeth were bonded with 0.018-inch stainless steel maxillary central incisor brackets (Victory Series, 3M/Un-

TABLE 1. Light Tip Size and Intensity of the Three Light Curing Units Tested at Different Distances From the Bracket Base

Light ^a	Tip Size, mm	Distance, mm	Group	Light Intensity, mW/cm ²
HL	7.5	0	1	1100
			2	715
			3	350
LED	7.5	0	4	700
			5	300
			6	175
PAC	8	0	7	1200
			8	1075
			9	950

^a HL indicates halogen light; LED, light-emitting diode; and PAC, plasma arc.

itek, Monrovia, Calif) by one operator. The average bracket base surface area was reported by the manufacturer to be 11.7 mm². This was verified by measuring it with a digital caliper (Mitutoyo, Miyazaki, Japan). The area of 15 brackets was recorded, and the mean value was calculated for each group.

Bonding procedure

Before bonding, the facial surface of each incisor was cleaned for 10 seconds with a mixture of water and fluoride-free pumice in a rubber polishing cup, using a low-speed handpiece. The enamel surface was water-rinsed to remove pumice or debris and dried with an oil-free air stream.

Teeth were etched with 37% phosphoric acid gel (3M/Unitek) for 30 seconds, followed by thorough washing and drying. A thin layer of XT primer (Transbond XT, 3M/Unitek) was applied on the etched enamel, and the brackets were bonded with the composite resin (Transbond XT, 3M/Unitek) near the center of the facial surface of the tooth. Sufficient pressure was used to express excess adhesive, which was removed from the margins of the bracket base with a scaler before polymerization.

Light curing units

The three different light curing units used in the present investigation were a high-intensity halogen light (Astralis 10, Ivoclar-Vivadent, Schaan, Liechtenstein), a LED (e-Light, GC Europe, Leuven, Belgium), and a plasma arc light (PAC System, American Dental Technologies, Corpus Christi, Tex). The three light curing units were used at three different light-tip distances from the bracket, ie, zero, three, and six mm. The distance of the curing tip was standardized for each light by placing the specimen on a graph paper that had a predetermined line representing the exact distance and angulation from the bracket base. Moreover, a metallic piece of wire with the predetermined distance from the bracket base (zero, three, and six mm) was used and superimposed onto the previous line. A diagrammatic rep-

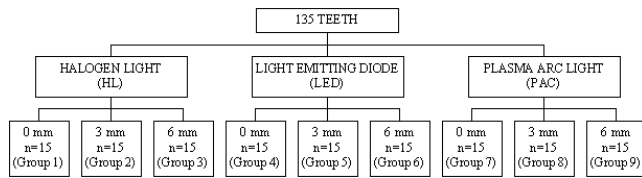


FIGURE 1. Diagrammatic representation of study specimen grouping.

resentation of the study design is illustrated in Figure 1. The light-tip size (mm) and intensity (mW/cm^2) of each light curing unit at the three different distances are presented in Table 1. Light intensity was measured with a radiometer (Demetron, SDS Kerr, Danbury, Conn).

Following the manufacturers' instructions, the brackets were cured with the halogen light for five seconds on the mesial and five seconds on the distal side (total cure time: 10 seconds in high-power mode). The brackets were cured with the LED for three seconds on the mesial and three seconds on the distal side (total cure time: six seconds in fast-cure mode). The brackets were cured with the plasma arc light for two seconds on the mesial and two seconds on the distal side (total cure time: four seconds).

Debonding

After bonding, all samples were stored in distilled water at room temperature for 24 hours and subsequently tested in a shear mode on a universal testing machine (Erichsen 469 LE4, 500 N, Wuppertal, Germany), according to the draft of ISO specification TC 106/SC 2/WG 16. Specimens were secured in the lower jaw of the machine so that the bonded bracket base was parallel to the shear force direction. Specimens were stressed in a gingivocclusal direction at a crosshead speed of 1 mm/min, as in previous studies.^{2,28,29} The maximum load necessary to debond or initiate bracket fracture was recorded in newtons and converted to megapascals as a ratio of newtons to surface area of the bracket.

Residual adhesive

After bond failure, the bracket bases and the enamel surfaces were examined by the same operator. The Adhesive Remnant Index (ARI) was used to assess the amount of adhesive left on the enamel surface.³⁰ The ARI scores range from 0 to 3: "0" indicates no adhesive remained on the tooth in the bonding area; "1," less than half the adhesive remained on the tooth; "2," more than half the adhesive remained on the tooth; and "3," all adhesive remained on the tooth, with a distinct impression of the bracket mesh.

Statistical analysis

Descriptive statistics were calculated for each of the nine groups. A two-way analysis of variance (ANOVA) was applied to determine whether significant differences in debond values existed among the various groups. For post hoc test, a Scheffé's test was used.

The chi-square (χ^2) test was used to determine significant differences in the ARI scores among the different groups. The level of significance for all statistical tests was set at $P < .05$. All statistical analyses were performed with Stata seven Program (Stata Corp, College Station, Tex).

RESULTS

Descriptive statistics for shear bond strengths are presented in Table 2. The results of the ANOVA indicated the presence of significant differences among the various groups ($P = .000$). When comparing the three light curing units at a light-tip distance of zero mm (groups 1, 4, and 7), no significant differences were reported in terms of shear bond strengths ($P = .17$). On the other hand, at distances of three mm (groups 2, 5 and 8) and six mm (groups 3, 6 and 9), no significant differences were found between the halogen and plasma arc lights ($P > .44$), but both showed significantly higher shear bond strengths than the LED light ($P < .16$).

When using the halogen light and evaluating the effect of the light-tip distances on each light curing unit, no significant differences ($P = .52$) were found among the three

TABLE 2. Descriptive Statistics (in MPa) of Shear Bond Strengths of the Nine Groups Tested (Each Group Consisted of 15 Specimens)

Light ^a	Distance, mm	Group	Mean	SD	Minimum	Median	Maximum	Scheffé ^b
HL	0	1	23.7	7.3	9.1	26.2	34.2	A, F
	3	2	21.9	5.7	14.7	20.9	31.9	B, F
	6	3	24.4	5.2	14.2	25.7	30.2	D, F
LED	0	4	19.9	5.7	10.0	20.3	28.0	A, C
	3	5	14.8	7.5	5.1	14.4	28.8	C, E
	6	6	9.6	5.3	3.4	8.8	20.5	E
PAC	0	7	20.2	4.9	9.9	21.2	27.6	A, B
	3	8	24.1	6.0	12.9	25.4	34.1	B, D
	6	9	27.0	5.6	12.8	29.1	31.1	D

^a HL indicates halogen light; LED, light-emitting diode; and PAC, plasma arc.

^b Scheffé grouping. Means with the same letter are not significantly different.

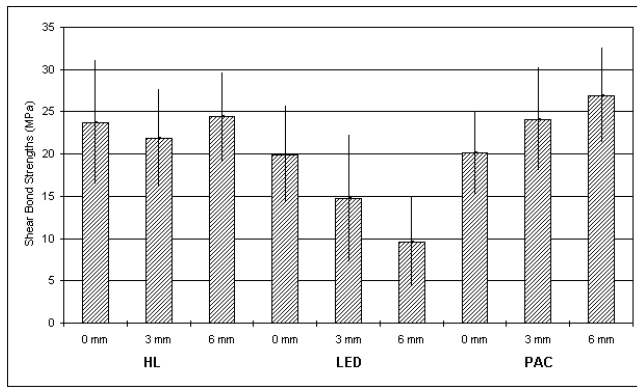


FIGURE 2. Mean shear bond strengths (MPa) of the three curing units under the three different light-tip distances (zero, three, and six mm). HL = halogen light; LED = light-emitting diode; PAC = plasma arc light.

distances (groups 1, 2, and 3). Using the LED light, no significant differences ($P > .087$) were reported between groups 4 (zero mm) and 5 (three mm) and between groups 5 (three mm) and 6 (six mm). On the other hand, a significant reduction ($P = .000$) in bond strength value was found when comparing group 4 (zero mm) with group 6 (six mm). Using the PAC system, no significant difference ($P > .16$) was found between groups 7 (zero mm) and 8 (three mm) and between groups 8 (three mm) and 9 (six mm), whereas a significant increase ($P = .007$) in bond strength was reported when comparing group 7 (zero mm) with group 9 (six mm) (Figure 2).

The ARI scores for the nine groups tested are listed in Table 3. When comparing the three lights for each light-tip distance, the χ^2 test results indicated no significant differences ($P > .3$) in ARI scores for the three lights at each tested distance (zero, three, and six mm). When evaluating the effect of the light-tip distance on each light curing unit, no significant differences ($P > .41$) in ARI scores were found among the three distances for all the light curing units (halogen, LED, and plasma arc).

DISCUSSION

The null hypothesis of the study was rejected. The present investigation demonstrated that the three light curing

units showed no statistically different shear bond strengths at a light-tip distance of zero mm. At greater distances of three and six mm, no significant differences were found between the halogen and plasma arc lights, but both revealed significantly higher shear bond strengths than the LED light.

There are no studies in the literature that have compared the shear bond strengths of halogen, LED, and plasma arc lights used at different light-tip distances from the brackets. Previous investigations that compared the shear bond strengths of brackets cured with LED with those of brackets cured with conventional halogen lights showed no significant differences between these two lights.^{22,23} Other authors compared the bond strength of halogen and plasma arc lights and reported no significant differences between these two lights.^{2,11-13} This is in agreement with the present investigation, where no significant differences between the three curing units were found at a light-tip distance of zero mm from the bracket.

Moreover, in the present study the effect of light-tip distance on the shear bond strength of each light curing unit was investigated. When using the halogen light, the light-tip distance did not significantly affect the bond strength values. However, when using the LED light, a greater light-tip distance produced lower shear bond strengths, with a significant reduction at a light-tip distance of six mm from the bracket base. On the other hand, using the plasma arc light, a greater light-tip distance produced higher shear bond strengths, with a significant increase at six mm from the bracket base. As illustrated in Table 1, the light intensity of the LED light had a 58% decrease at three mm and a 75% decrease at six mm, compared with the intensity measured at zero mm. On the other hand, the plasma arc light showed a 11% and 21% decrease in light intensity at three and six mm, respectively. Thus, it could be hypothesized that because the intensity of the plasma arc light is very high, increasing the distance of the light tip from the bracket base could allow for curing a wider area of the enamel surface, without a significant decrease in power output.

To date, there are no published studies that evaluated the effect of light-tip distance on the shear bond strengths of orthodontic brackets cured with LED and plasma arc lights.

TABLE 3. Frequency of Distribution of ARI Scores (%)^a

Group	ARI = 0	ARI = 1	ARI = 2	ARI = 3
Group 1—HL—0 mm	1 (6.7)	2 (13.3)	1 (6.7)	11 (73.3)
Group 2—HL—3 mm	3 (20.0)	3 (20.0)	0 (0.0)	9 (60.0)
Group 3—HL—6 mm	5 (33.3)	1 (6.7)	0 (0.0)	9 (60.0)
Group 4—LED—0 mm	1 (6.7)	0 (0.0)	0 (0.0)	14 (93.3)
Group 5—LED—3 mm	1 (6.7)	1 (6.7)	0 (0.0)	13 (86.7)
Group 6—LED—6 mm	3 (20.0)	1 (6.7)	1 (6.7)	10 (27.0)
Group 7—PAC—0 mm	2 (13.3)	2 (13.3)	0 (0.0)	11 (73.3)
Group 8—PAC—3 mm	0 (0.0)	2 (13.3)	1 (6.7)	12 (80.0)
Group 9—PAC—6 mm	1 (6.7)	0 (0.0)	2 (13.3)	12 (80.0)

^a ARI indicates adhesive remnant score; HL, halogen light; LED, light-emitting diode; and PAC, plasma arc.

Caldas et al²⁶ evaluated the effect of light-tip distance on the hardness of composite resins and reported that the halogen, LED, and plasma arc units showed a decrease in the resin composite hardness as the light-tip distance increased. Another investigation evaluated the decrease in power output of LED curing devices with increasing distance to the filling surface.³¹ The authors found that although blue LED curing devices might have the same curing potential as a halogen device when placed in direct contact with a resin composite, blue LED curing devices may not provide a sufficient cure when placed at a distance of 10 mm to the resin composite surface. This decrease in power output can explain the lower shear bond strength values achieved in our investigation when the LED curing light was placed at a light-tip distance of six mm.

Reynolds³² suggested that minimum bond strength of six to eight MPa was adequate for most clinical orthodontic needs. In the present work, the bond strengths of the three light curing units used at the three different light-tip distances from the bracket base exceeded these limits.

No significant differences in ARI scores were reported among the three curing lights at the three distances tested, and no significant differences were found among the three light-tip distances for each light curing unit. A higher frequency of ARI scores of 3 was reported for all the groups tested, indicating that the entire adhesive remained on the tooth with a distinct impression of the bracket mesh. Previous studies that compared the ARI scores of halogen and LED curing lamps showed no significant differences between the two lights, in agreement with our findings.^{22,24,25} Other reports evaluated the ARI scores of halogen and plasma arc lamps and showed a significantly higher frequency of bond failure at the bracket-adhesive interface (ARI score of 3) when the composite resin was cured with a conventional halogen light.^{2,12} The composite resin cured with the xenon arc light showed a significantly higher frequency of bond failure at the enamel-adhesive interface (ARI score of 0), in contrast with the present findings. The variability of the results may be attributed to the differences in the mechanical and physical properties of the materials tested in each study.

CONCLUSIONS

With the limitations of this *in vitro* study, the following conclusions may be drawn:

- When used at a distance of zero mm from the bracket, the three light curing units showed no statistically different shear bond strengths.
- At distances of three and six mm, no significant differences were found between the halogen and plasma arc lights, but both had significantly higher shear bond strengths than the LED light.
- The halogen light showed that no significant differences in bond strength were found among the three distances.

Using the LED light, a greater light-tip distance produced significantly lower shear bond strengths, whereas using the plasma arc lamp, a greater light-tip distance caused significantly higher shear bond strengths. Therefore, in hard-to-reach areas, the use of PAC system is suggested, whereas the e-Light is not recommended.

- All the combinations tested showed bond strengths that could be clinically acceptable, although big differences existed among them.
- No significant differences in ARI scores were found among the various groups.

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